How Can Poland Comply with Kyoto and Europe's Second Sulfur Protocol? An Analysis of Various Energy Supply Scenarios and Their Implications for Future Air Pollution Emissions*

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ABSTRACT

Poland's move to restructure and modernize its economy in preparation for joining the European Union will go hand in hand with major changes in the way the country produces and consumes energy. A projected increase in energy consumption must be balanced with domestic and international environmental obligations to reduce source emissions. As signatory to both the European Second Sulfur Protocol, as well as the Kyoto Protocol, the country has agreed to significantly reduce its emissions of sulfur dioxide (SO_2) and greenhouse gases by 2010. This study uses the ENergy and Power Evaluation Program (ENPEP) to analyze several energy policy scenarios and to identify those that meet the requirements of both protocols. The results show that Poland will be able to meet the SO_2 emission requirements under all scenarios. However, meeting the Kyoto obligations will strongly depend on which reference year Poland will ultimately consider as binding.

INTRODUCTION

Stationary sources constitute the largest source of air pollution in Poland. In 1995, they accounted for about 63% of nitrogen oxide (NO_X) emissions, 93% of carbon dioxide (CO_2) emissions, and 99% of sulfur dioxide (SO_2) emissions. The electric power sector, including public combined heat and power plants (CHP) and public heat plants, is one of the largest contributors with 52% of SO_2 and 53% of CO_2. Historical emission trends are shown in Figure 1. Emission levels for all air pollutants declined significantly from 1988 to 1994, as a result of the general decline in economic activity and energy demand. Inefficient factories were closed during this period as Poland began to enter into the world market.

Current emission levels in Poland are somewhat comparable to those of the United Kingdom (UK), as shown in Figure 2. However, as Figure 3 indicates, related to the economic activity of the country (expressed in terms of gross domestic product [GDP]), air emissions in Poland are much higher than in other European countries, especially compared with France, Finland, or Sweden. Emissions of SO_2 per unit of GDP are of particular concern because they are approximately 5.2 times higher than in the UK, 5.7 times higher than in Germany, and much higher than the average for European Organization for Economic Cooperation and Development (OECD) countries. Similarly, Poland's CO_2 emissions per unit of GDP of 3.2 kg CO_2/US$94 are about 5.1 times higher than those of Germany. This pattern emerged because Poland's energy system is heavily coal-based, rather than nuclear (France) or non-coal mixes (Sweden, Finland). Also, Poland's economy is geared more toward energy-intensive industries, such as raw steel and aluminum with relatively low prices, whereas Western European countries produce high-quality finished products.

In the context of restructuring and modernizing its economy and preparing to join the European Union, Poland is determined to bring its emissions in line with its Western European neighbors. Poland has demonstrated its commitment to doing so by signing the Kyoto Protocol and the European Second Sulfur Protocol to the Convention on Long-Range Transboundary Air Pollution. The Second Sulfur Protocol obligates Poland to reduce its SO_2 emissions to 2.173 million metric tons after 2005 and 1.397 million metric tons after 2010. Under the Kyoto Protocol, Poland agreed to reduce its CO_2 emissions by 6% below the reference year level. Poland has indicated that it intends to use the flexibility option provided in the Kyoto protocol, which allows countries with economies in transition to choose a base year other than 1990. In the national communication to the Conference of the Parties to the United Nations Framework Convention on Climate Change, the case was made to use 1988 as the reference year for Poland's commitments.[1] However, as part of the impending integration into the European Union, Poland might have to commit to further reductions and use 1990 as base year instead.[2] The reduction commitment under the latter case would be significantly more stringent.

This paper examines a variety of energy sector development scenarios and analyzes their effects on projected air pollution emission levels under each scenario so as to compare them with Poland's international emission reduction commitments. It also discusses the significance for Poland of choosing the base year for its Kyoto obligations. The ENergy and Power Evaluation Program (ENPEP) was used to conduct the analysis. A business-as-usual scenario is compared with two other scenarios that include incentives for switching fuel from coal to natural gas in all sectors, one scenario that attempts to incorporate external environmental costs into the analysis, and one scenario that looks at the implications of rehabilitating a majority of Poland's existing coal-fired thermal plants.

PAST AND CURRENT ENERGY SITUATION

Poland's primary energy supply has historically been dominated by coal (Figure 4). The solid fuel share in the early 1970s was around 80 to 82%; by 1995, it still was over 70%. A noticeable decline in the use of hard coal consumption was observed after 1989 following the dramatic reduction in domestic demand as part of the country's economic transition. Coal is consumed by the power sector where all of the major generating units burn either hard coal or lignite. Coal is also used for district heating, which is mostly based on coal, as well as in the industrial, commercial, and residential sectors. The oil share increased from 11% in the early 1970s to 14% in 1995, primarily because of the recent growth in diesel and gasoline demand in the transportation sector. The gas share increased from 6% in 1971 to 9.3% in 1995 because of fairly rapid growth in the distribution pipeline network and household use. Hydroelectricity production (excluding pump-storage plants) accounts for only a few tenths of a percent of the total primary energy supply. The biomass (primarily wood) share, which was only about 1% through 1991, grew rapidly in the early 1990s to 3.5% in 1995.

Total annual electricity production increased from 122 TWh in 1980 to 146 TWh in 1989, but declined to 133 TWh by 1992. Since then, power generation has increased an average of about 2% annually. The total installed generating capacity in 1995 was 33,116 MWe, out of which 91% are publicly owned and 9% are owned by autoproducers. The largest thermal power plant is the lignite-fired Belchatow plant with 4,320 MW of installed capacity. Electricity is produced mainly from solid fuels. Approximately 62% of the public generating capacity is hard coal-fired, 31% is lignite-fired, and 7% is hydro. A large majority of the units are more than 30 years old and have low efficiencies.

District heating networks supply 53% of Poland's total residential heating needs. Heat plants operated by the district heating enterprises account for a little less then a third of Poland's electric generating capacity. The average efficiency of heat production varies from 78% for the public CHP plants to less than 50% for smaller plants. There are no automatic control systems, and there is almost no metering of delivered heat. Other problems include pipe corrosion, leaks, failures, and interruptions in supplies. Water losses from district heating systems are about four times higher in Poland than in Western Europe, and heat losses are estimated to be between 10 and 45%.

Total final energy consumption (TFEC) increased steadily until 1980. It stagnated in the 1980s, declined sharply after 1988, and increased gradually to present day (1995) levels of 67 Mtoe. The share of solid fuels in the TFEC declined from 52% in 1971 to about 40% in the 1990s. Though the share of electricity increased from 7% in 1971 to about 11% in 1995, it is still considerably less than in Western Europe. Both oil and gas shares increased from 13 to 19% and from 7 to 12%, respectively. The share of heat has held steady at 22 to 25% for more than two decades, which reflects the importance of heat in Poland's final energy consumption and the fact that household energy use fluctuates less with economic conditions than that of the other sectors. Currently, the residential sector accounts for a majority (i.e., 63%) of heat consumption.

In general, Poland's economy is very energy intensive. Despite recent achievements in its economic restructuring process, its share of heavy industry and manufacturing is still significantly larger than that of industrialized countries such as France, Sweden, and the United Kingdom. Additional factors that contribute to the overall low energy efficiency observed in Poland include (1) low process efficiencies of aging capital stock, (2) inadequate attention to sound management practices, (3) the substantial share of solid fuels and associated low conversion efficiencies in the residential sector, and (4) the low penetration of new and more efficient equipment.

MODELING APPROACH

Figure 5 shows the modeling framework and the three modules of the ENPEP Model that were used for the study.[3, 4] Since Poland has undergone very radical changes in the recent past, historical trends cannot be used as a tool for forecasting the country's future under a market-based economy. Instead, data for five select OECD countries (Finland, France, Germany, Great Britain, and Sweden) were used as surrogates for the energy demand forecasts. Statistical analyses on relationships between macroeconomics and energy consumption for these countries were combined with results from Poland's dynamic macroeconomic model. The model was used to forecast key economic activities such as sectoral value added under scenarios that are consistent with recent projections by the European Union.[5] Other factors considered in the energy demand forecast include assumptions concerning the market penetration rate of state-of-the-art technologies and the rate at which the Polish economy will be restructured. Energy demand projections were performed for both final energy demand and useful energy demand. Primarily because of insufficient data, useful energy demand was projected only for the residential and commercial sectors, and parts of the industrial sector. Final energy demand projections were performed for all sectors.

The main module or focal point of the modeling system is the BALANCE Module of ENPEP. BALANCE uses a nonlinear, equilibrium approach to determine the energy supply and demand balance. The model uses an energy network that is designed to trace the flow of energy from primary resource (e.g., crude oil, coal) through to final energy demand (i.e., diesel, fuel oil) and/or useful energy demand (i.e., residential hot water, industrial process steam). Figure 6 shows an example for the residential space heating subsector. Demand for fuels is sensitive to the prices of alternative supplies, and supply prices are sensitive to the quantity demanded. In its operation, BALANCE simultaneously finds the intersection of supply and demand curves for all energy supply forms and all energy uses that are included in the energy network. The equilibrium is reached when the model finds a set of prices and quantities that satisfy all relevant equations and inequalities.

The BALANCE Module requires detailed information on the electric sector and the additional generating resources that must be acquired to replace retired units and to meet the growth in electricity demand. The least-cost capacity expansion plan is determined by the ELECTRIC Module of ENPEP and is transferred to BALANCE. To determine this expansion path, ELECTRIC requires a forecast of fuel costs that are projected by BALANCE. Any potential inconsistencies between the two models are resolved iteratively.

Emissions of environmental residuals that are the result of energy extraction, conversion processes, and consumption are computed by the IMPACTS Module of ENPEP. Energy activity forecasts at each node in the BALANCE Module are transferred into IMPACTS. The module estimates both controlled and uncontrolled emissions throughout the study period as well as environmental compliance costs. Environmental control strategies and technologies affect capital expenditure for new unit construction along with operational efficiencies and costs. The control strategy information from IMPACTS is transferred into both the BALANCE and ELECTRIC Modules.

The following energy policy scenarios were analyzed using the above framework:

1) Business as Usual (BAU): Under the BAU scenario, Poland's current energy policies remain largely unchanged. The country's existing thermal power plants will not be rehabilitated and will gradually be retired.

2) Increased Gas (GAS): The GAS scenario includes economic incentives to encourage fuel switching from coal to natural gas. This is accomplished by implementing a tax across all sectors on all types of coals, including coke, for residential space heating. Two subscenarios, or tax levels, were considered: a 30% tax (GAS-30) and a 50% tax (GAS-50), both starting in 2000.

3) Maintain Coal (COA): This scenario is similar to the BAU scenario but looks at the implications of rehabilitating the majority of Poland's thermal power plants. The rehabilitation will allow the units to operate an additional 120,000 hours and to use the original design fuel, that is, hard coal and lignite. Under this scenario, the efficiency of the existing thermal plants will improve, and the units will be retrofitted with flue gas desulfurization to control SO_2 emissions. Most existing power units will remain on-line for the entire forecast period.

4) External Cost (EXC): The EXC scenario is an attempt to identify the effects of incorporating external environmental costs into the cost of electric power generation. Generation costs of new candidate technologies were increased by an external environmental cost that varies by fuel type. The following values were used in the model runs: 64 mills/kWh for coal, 39.5 mills/kWh for oil, and 21.5 mills/kWh for natural gas.[6] The external costs account for health damages for a variety of pollutants, such as SO_2, NO_X, PM_{10}, VOC, CO_2, and heavy metals. The costs are consistent with estimates made under the European ExternE project.

RESULTS

Under the medium economic forecast, Poland's GDP is projected to grow at an annual average growth rate of 4.1% (1.2% for low and 6.1% for high), from 201 billion US$90 in 1996 to about 527 billion US$90 by 2020. This growth in GDP is in contrast to a fairly modest increase in total final energy demand of 0.9% under the medium forecast, from 73 Mtoe in 1996 to 91 Mtoe by 2020 (Figure 7). The difference is especially discernable between 1996 and 2005. While GDP grows a total of 56% over this time period, final energy demand remains constant under the medium forecast. This is based on an assumed increase in energy conservation measures, similar to increases observed in select OECD countries during the 1970s and 1980s. Also, an accelerated change in efficiency improvements is assumed where current state-of-the-art appliances will replace existing technologies during this 10-year period, and thus keep total final energy demand constant. After 2005, final energy demand grows at a modest annual average rate of 1.5%. The low- and high-growth forecasts represent extreme projections of Poland's future. Under the high-growth forecast, the country's economy grows at a rapid rate along with a unified and harmonious Europe. In the low-growth forecast, European countries do not cooperate with each other. The energy development scenarios discussed in the remainder of this paper are based on the medium demand growth forecast.

Under the BAU scenario, the coal share in the total primary energy supply (TPES) is estimated to drop from about 73% in 1995 to 56% by the year 2020 (Figure 8). The decrease in coal share is in response to a rise in natural gas of about 91% for electricity generation and for direct use in various end-use sectors. Also, the increase in oil to cover the growing transportation demand contributes to the reduction in coal share as well. With the exception of COA, the coal share under the alternative scenarios is expected to decrease more rapidly and by 2020 may reach as low as 33% under EXC. The natural gas penetration is accelerated and is projected to more than triple (222% rise). Also, as the coal price increases significantly under the EXC, GAS-30, and GAS-50 scenarios, nuclear power will become economically viable for base-load generation and is forecast to provide 11 to 15% of TPES.

Total CO_2 emissions under BAU are estimated to grow at a modest average annual rate of 0.7% to 434 million metric tons by 2020 (Figure 9). The power industry remains the largest contributor throughout the study period and accounts for 45% of total emissions in 2020. Even though the majority of the existing thermal plants will be retired and replaced with modern gas and coal-fired units, the average growth in electricity demand of 3.8% per year results in a slow but constant growth (0.8% per year) in electric sector-related CO_2 emissions. The projected strong growth in Poland's transportation demand makes the transport-related CO_2 emissions grow at an average rate of 3.1% per year. This is more rapid than any other economic sector. Transport-related CO_2 emissions almost double their share, from 8% in 1996 to 14% by 2020, and account for almost 38% of the growth in CO_2 emissions.

Sulfur dioxide emissions under the BAU scenario are projected to decline to 1.165 million metric tons. As shown in Figure 10, the bulk of the drop in emissions can be attributed to changes in the electric power sector and accounts for about 80% of the decline. This is a result of the projected installation of flue gas desulfurization (FGD) at existing thermal generating units, such as Belchatov, Patnov, Jaworzno, and Polaniec, as well as the assumed gradual retirement of a large share of Poland's currently operating thermal plants. The replacement capacity for the retired units is provided by new gas-fired stations and new coal units equipped with FGD. Also, the projected economic shift to the relatively low-emitting residential/services sector contributes to the decrease in emissions. Industrial emissions grow at a very modest rate because of increased efficiencies and a shift from high-polluting heavy industries to less-polluting light manufacturing. However, their share continuously increases as total emissions decrease, and by 2020, Poland's industry is expected to be the largest source of SO_2 emissions, accounting for 37% of the total.

Figures 11 and 12 present the results of the GAS-50 scenario as an example of where additional emission reductions will be realized under the alternative scenarios. CO_2 emission mitigation under GAS-50 is estimated at 84 million metric tons by 2020 (equivalent to a 19% reduction below BAU levels) and will be achieved mainly in the electric power sector with minor reductions in the heat, industrial, and fuel supply sectors. Under the GAS and the EXC scenarios, there is a stronger shift toward natural gas to expand the electric power system instead of new coal units under the BAU scenario. In addition, the introduction of nuclear power in the later years leads to additional emissions reductions compared to the BAU scenario.

The assumed use of FGDs under BAU reduces the potential under the alternative scenarios for additional major SO_2 emission abatement by fuel switching in the electric sector. SO_2 abatement under the GAS-50 scenario totals about 95,400 metric tons by 2020, equivalent to an 8% reduction. Still, approximately 72% of the mitigation occurs in the power industry, 18% in the heat sector, and the remainder in the industrial and fuel supply sectors. Figure 13 shows that meeting the SO_2 abatement requirements stipulated in the European Second Sulfur Protocol is possible under all scenarios analyzed. The differences among the scenarios are fairly small because additional fuel switching to gas and nuclear power in the electric industry under the GAS and EXC scenarios does not lead to significant additional emissions reductions compared with the FGDs that are assumed to be widely used under the BAU and COA scenarios. In the near-term, the COA scenario has the lowest SO_2 emissions. This is the result of extensive repowering and rehabilitation of existing units. However, in the long-term this scenario has the highest emissions because of its emphasis on coal use.

Figure 14 gives the total CO_2 emissions for all scenarios. Annual emissions by 2020 are forecast to be between 325 (EXC) and 434 million metric tons (BAU). The maximum CO_2 mitigation potential can be achieved under the EXC scenario with approximately 109 million metric tons by the year 2020, equivalent to a 25% reduction below BAU. As can be seen, all scenarios are projected to be well below the Kyoto requirements if based on 1988 as base year (1988-6%). Emissions in 1988 were significantly higher than in 1990 due to the dramatic decline in economic activity and associated emission levels observed in the early stages of Poland's transition to a market economy. Also, it reflects the fact that the scenarios displayed in Figure 14 are based on moderate economic growth assumptions. Clearly, should Poland's economy grow faster than projected, meeting the 1988-6% limit may be more difficult.

Comparing the emission projections with the Kyoto limit that is based on 1990 levels (1990-6%), the results show that only the EXC scenario will be able to meet the requirements during the commitment period of 2008 to 2012 and remain below the limit thereafter. On the basis of the average emission level during the 5-year commitment period, the two GAS scenarios are less than 1% higher than the l990-6% limit and remain fairly close to the limit after the commitment period.

The average price of electricity to the end user is forecast to grow at an annual rate of 1.8% under the BAU scenario. Under the alternative scenarios, the average price increase is higher because of the introduction of the coal taxes (GAS-30, GAS-50) and the incorporation of external environmental costs into the price of electricity (EXC). The COA scenario results in just slightly higher prices of electricity, as shown in Figure 15. Whereas both GAS and EXC lead to a noticeable increase in the electricity price above the BAU scenario. Under EXC, the price of electricity grows at an average annual rate of 2.7%. By 2020, the price of electricity is projected to be 25 to 28% above the BAU price level.

CONCLUSIONS

The targets of the Second Sulfur Protocol are projected to be met under every scenario. This is primarily because of the gradual replacement of old and inefficient generating units with new and state-of-the-art power plants, including coal units with FGD, gas-fired combustion turbines, or combined-cycle units under all scenarios. Nuclear unit additions are also made under the GAS and EXC scenarios. Emission reductions are forecast to come mostly from the electric power sector. As industrial emissions remain flat, this sector will become the largest source of SO_2 emissions by 2020. Future analyses will model the industry sector in more detail to better capture its emission reduction potential.

Poland is expected to meet the Kyoto requirements under all scenarios if 1988 (1988-6%) is used as base year for the calculations. However, as part of joining the European Union, Poland may be asked to reduce its CO_2 emissions further. The model results show that only under the scenario with external costs (EXC) will Poland be able to meet a 6% reduction below 1990 levels (1990-6%). The total CO_2 mitigation potential by 2020 is estimated at 109 million metric tons, or 25% of BAU levels. The price of electricity by 2020 in this case is projected to increase 25 to 28% above the levels projected for the BAU scenario.

For almost every scenario, the results show a growth in the natural gas share, mainly at the expense of hard coal. Under the GAS scenario, small-scale gas-fired CHPs achieve a fairly significant market penetration and are expected to replace many local solid fuel-fired emission sources.

DISCLAIMER

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FIGURES

Figure 1. Emission indices 1985 - 1994 (1990 = 100).
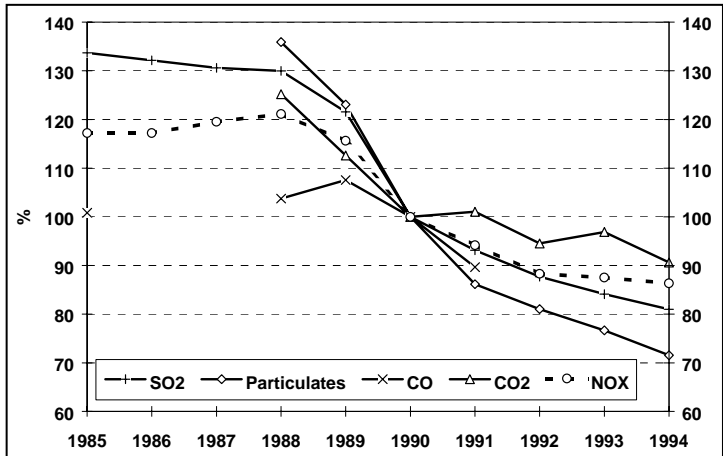
Figure 2. Comparison of 1995 national total emissions by country (1000 metric tons).

Country	SO$_2$	NO$_X$	NMVOC	CO$_2$	CO
Germany (1994)	2,995	2,210	2,153	897,000	6,748
United Kingdom	2,363	2,295	2,337	148,000	5,973
Poland	2,337	1,120	769	338,000	5,115
France	989	1,666	262	316,000	9,200
Sweden	94	362	446	63,000	1,058
Finland	96	259	185	56,000	434

Figure 3. Comparison of 1995 emissions per unit of GDP by country.
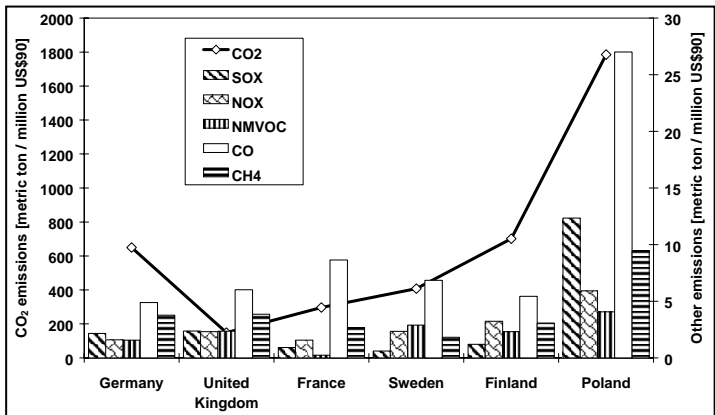
Figure 4. Primary energy supply 1970-1995.
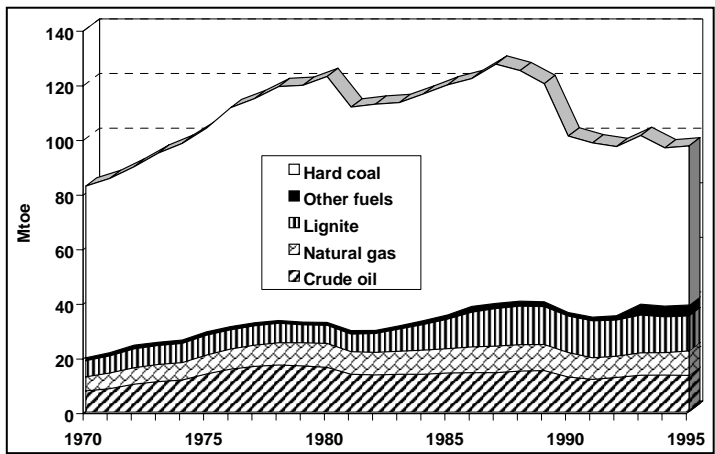
Figure 5. ENPEP modeling framework.
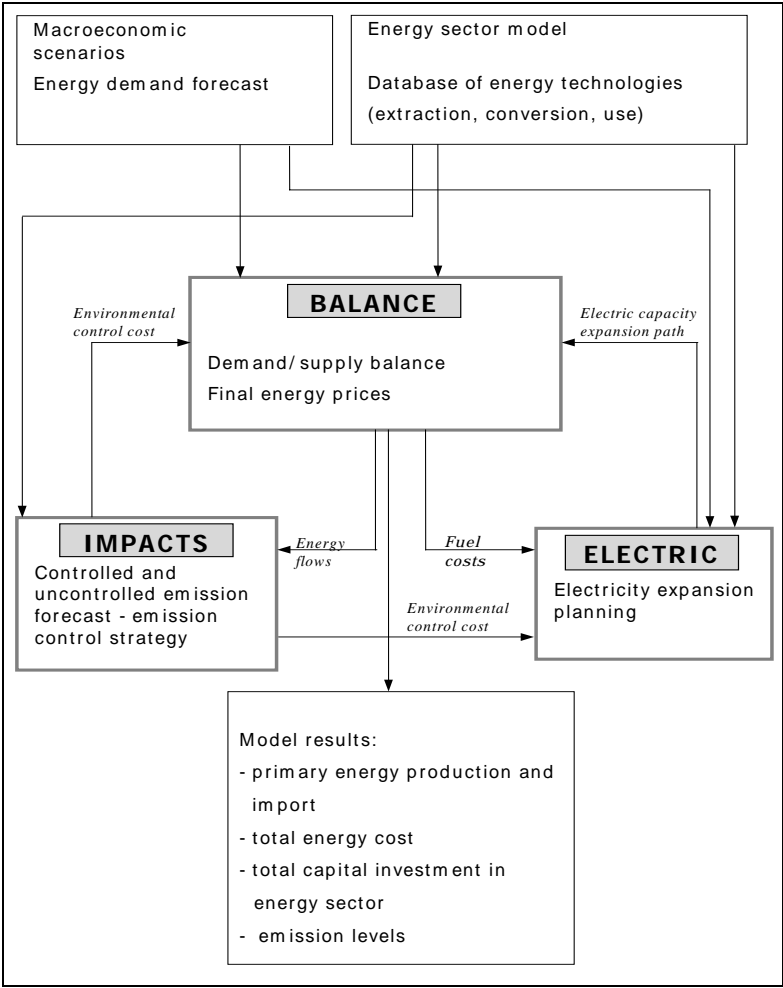
Figure 6. BALANCE network for residential space heating.
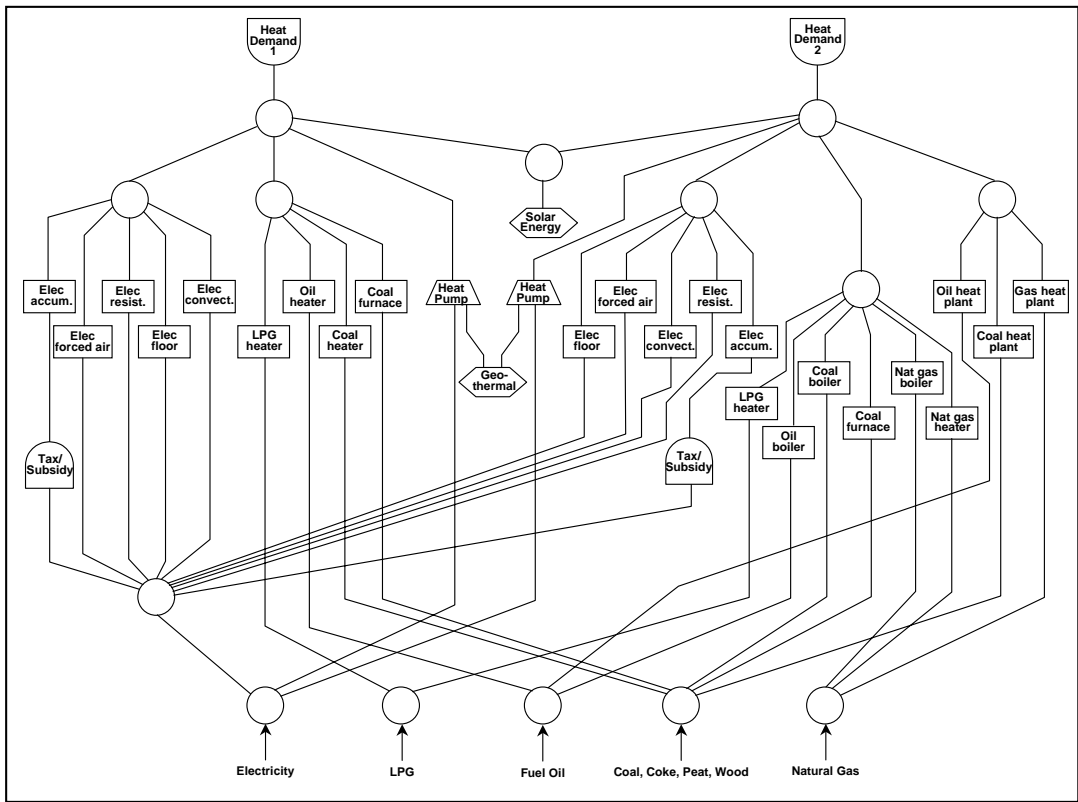
Figure 7. GDP and total final energy demand forecast.
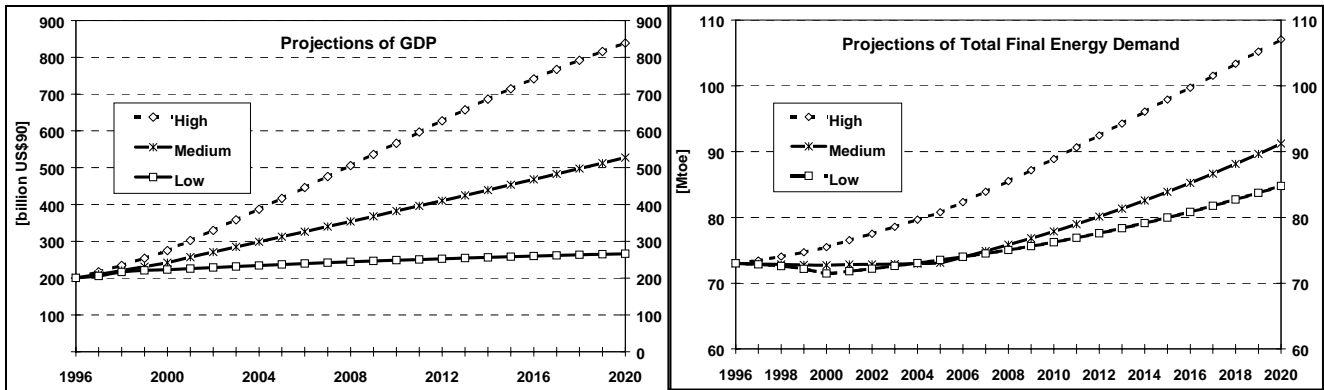
Figure 8. Projected primary energy supply mix by scenario.
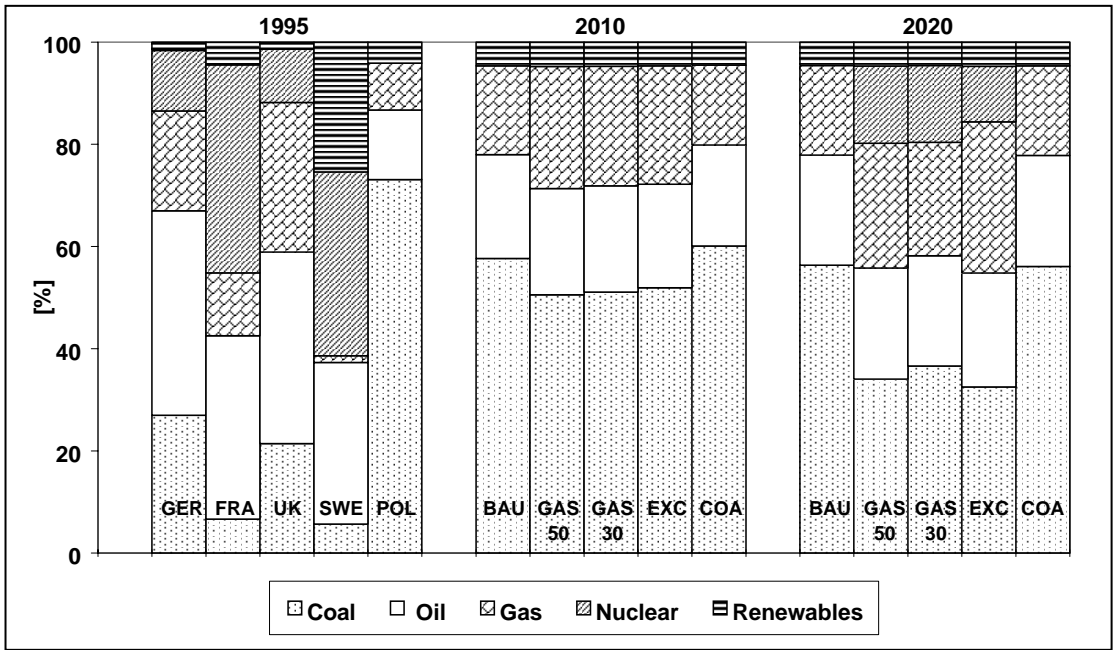
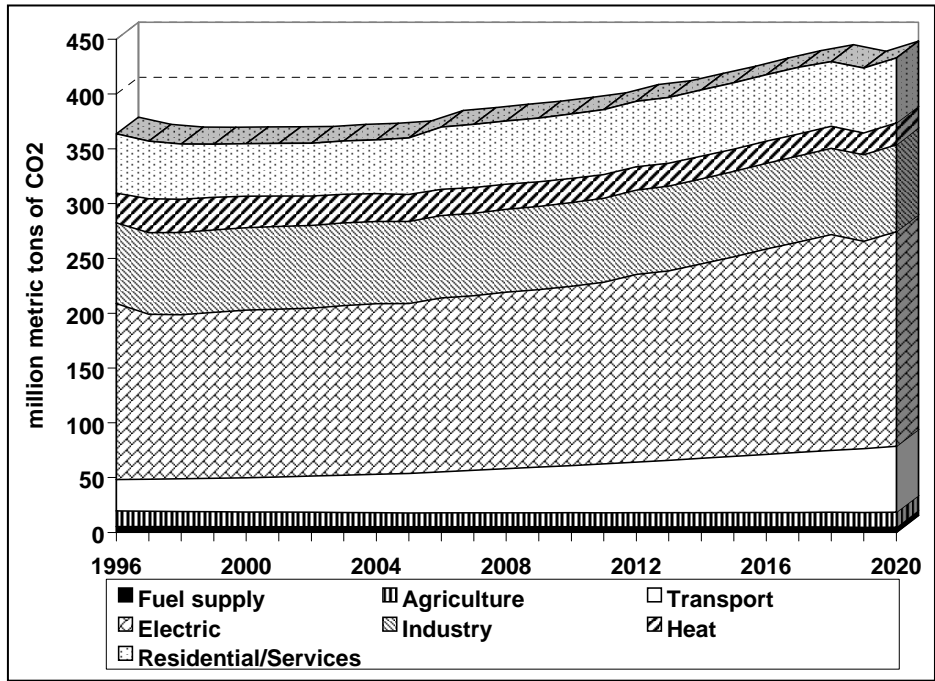**Figure 9.** Projected CO_2 emissions by sector under business-as-usual scenario.

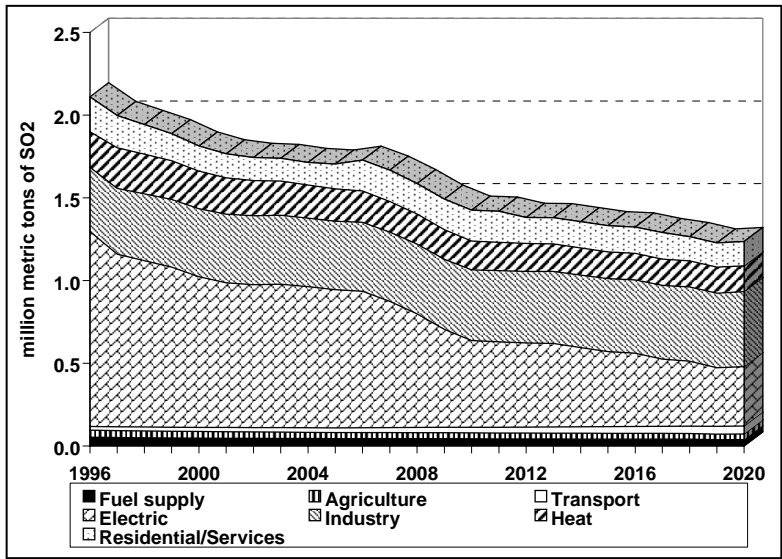**Figure 10.** Projected SO$_2$ emissions by sector under business-as-usual scenario.

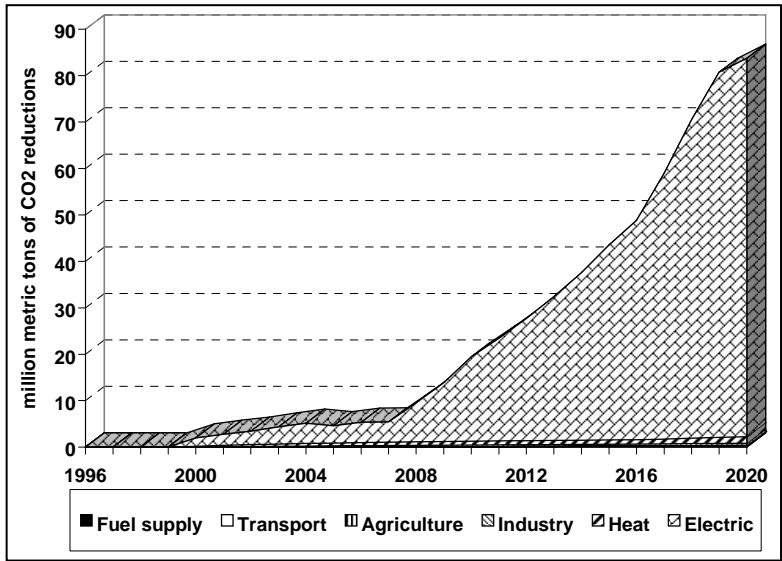**Figure 11.** Projected CO$_2$ emission reductions by sector under gas-50 scenario.

Figure 12. Projected SO$_2$ emission reductions by sector under gas-50 scenario.
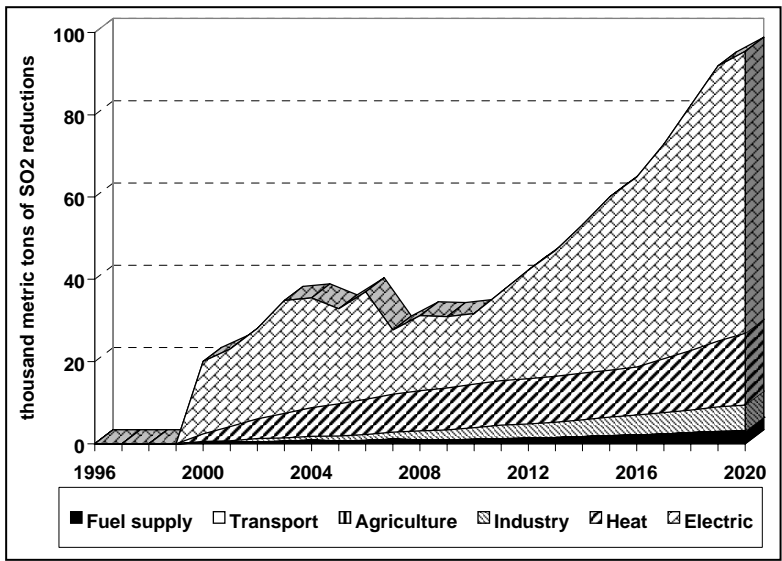
Figure 13. Projected SO₂ emissions by scenario.
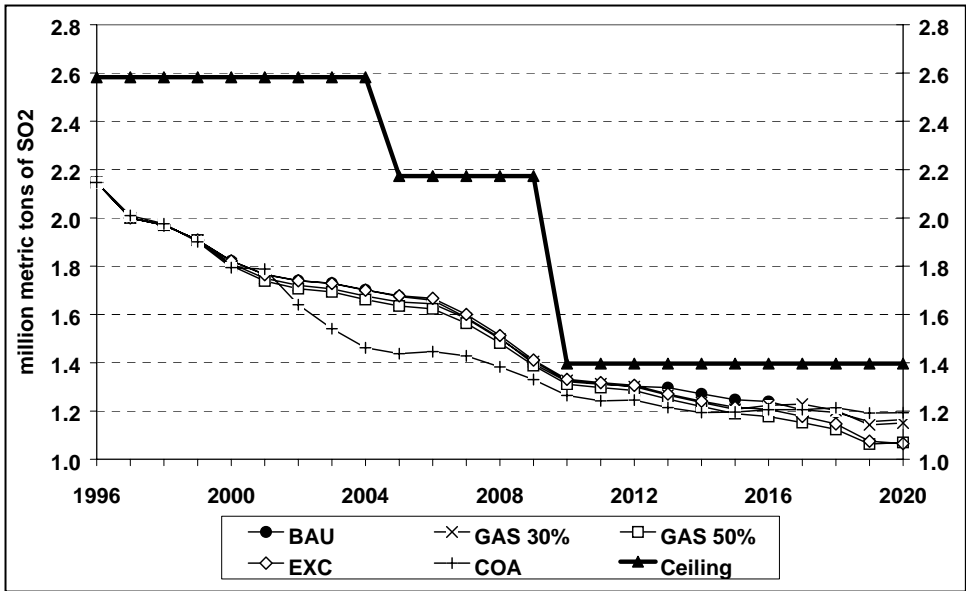

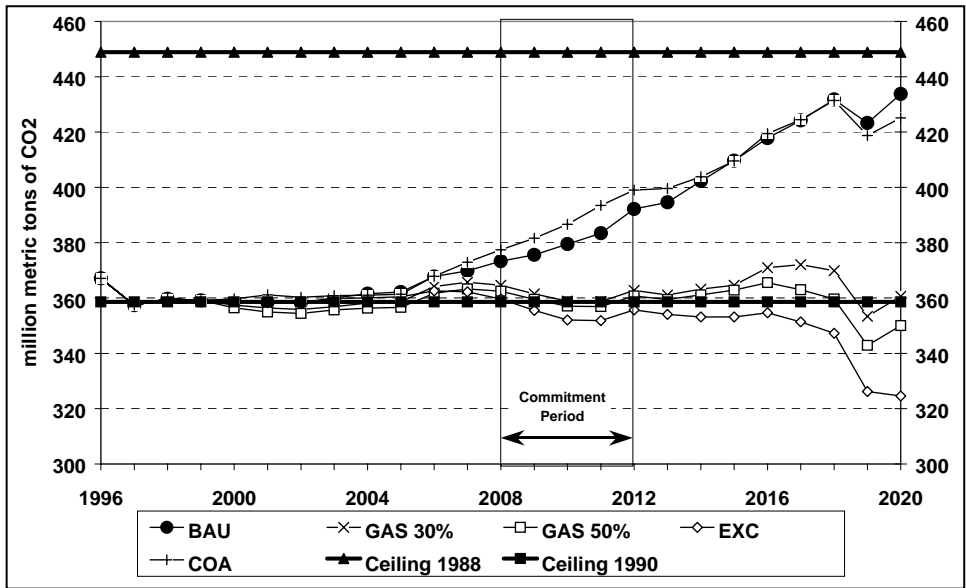**Figure 14.** Projected CO₂ emissions by scenario.

Figure 15. Projected change in residential electricity price by scenario.